



Low Latency Teleoperations for Mars Planetary Protection

Workshop on Planetary Protection Knowledge Gaps for
Human Extraterrestrial Missions

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- Background & Assumptions
- Notional Concepts, Tasks, Scenarios
- Gaps

Study Area 2: Technology and operations for contamination control

- Cleaning, sterilization, re-contamination prevention, and associated verification technologies for in-situ application
- Technologies for contamination control of human surface mobility systems and spacesuits
- **Human surface exploration operational strategies for mitigating contamination**
- Sample acquisition, containment and breaking-the-chain (BTC) of contact technologies
- Environmental clean-up of inadvertent release of unsterilized terrestrial material

The background of the slide is a composite image of space-related elements. On the left, a small portion of Earth is visible. Next to it is a large, detailed image of the Moon. In the center, the word "Background" is written in a large, white, sans-serif font. To the right of the text, there is a small image of an astronaut in a white spacesuit floating in space. Further right is a large, reddish-brown planet, likely Mars, with a small black object (possibly a meteorite or satellite) nearby. In the top right corner, the NASA logo is visible, featuring the word "NASA" in white on a blue circular background with a red swoosh.

Background

- Low-latency teleoperations (LLT) involves “real-time”, or near real-time, human operation of an asset at a distance.
- 2001: Pingree Park workshop cited role for teleoperations
- 2010: ESMD science architecture requirements work began to address PP implications, particularly test opportunities at Moon – OBE...
- 2011: HAT Destination Ops team noted opportunities to evaluate and practice contamination control and planetary protection measures, including roles for telerobotics in cis-lunar missions.
- **2012: HAT 500 day surface ops con noted many roles for low-latency teleoperations (LLT), including special region exploration.** Phobos-Deimos short stay feasibility study suggested LLT has potential benefits but needs further analysis.
- 2013: HAT Telerobotics and Crew-Assisted Sample Return task noted key roles for LLT, e.g. sample acquisition & handling.
- **2014: HAT Mars Moons Team is presently analyzing Mars surface tasks that could be done via LLT from Mars moons to Mars surface.**

The background of the slide is a dark space scene. At the top left, a small portion of Earth is visible. Next to it is a large, detailed view of the Moon's surface. In the center, the word "Assumptions" is written in a bold, white, sans-serif font. To the right of the title, an astronaut in a white spacesuit is shown floating in space. Further right is a large, reddish-brown planet, likely Mars, with a smaller dark object (possibly an asteroid or moon) nearby. In the top right corner, the NASA logo is displayed. The overall theme is space exploration and planetary science.

Assumptions

- Focusing on conservative cases that imply the need to keep human-source contamination out of a particular environment, suggesting possible roles for LLT as an alternative.
- While many tasks should and will be automated, it is assumed that many tasks will still benefit from “real-time” crew control, supervision, and intervention.
- Much of this material applies to other destinations such as asteroids and Moons of Mars.

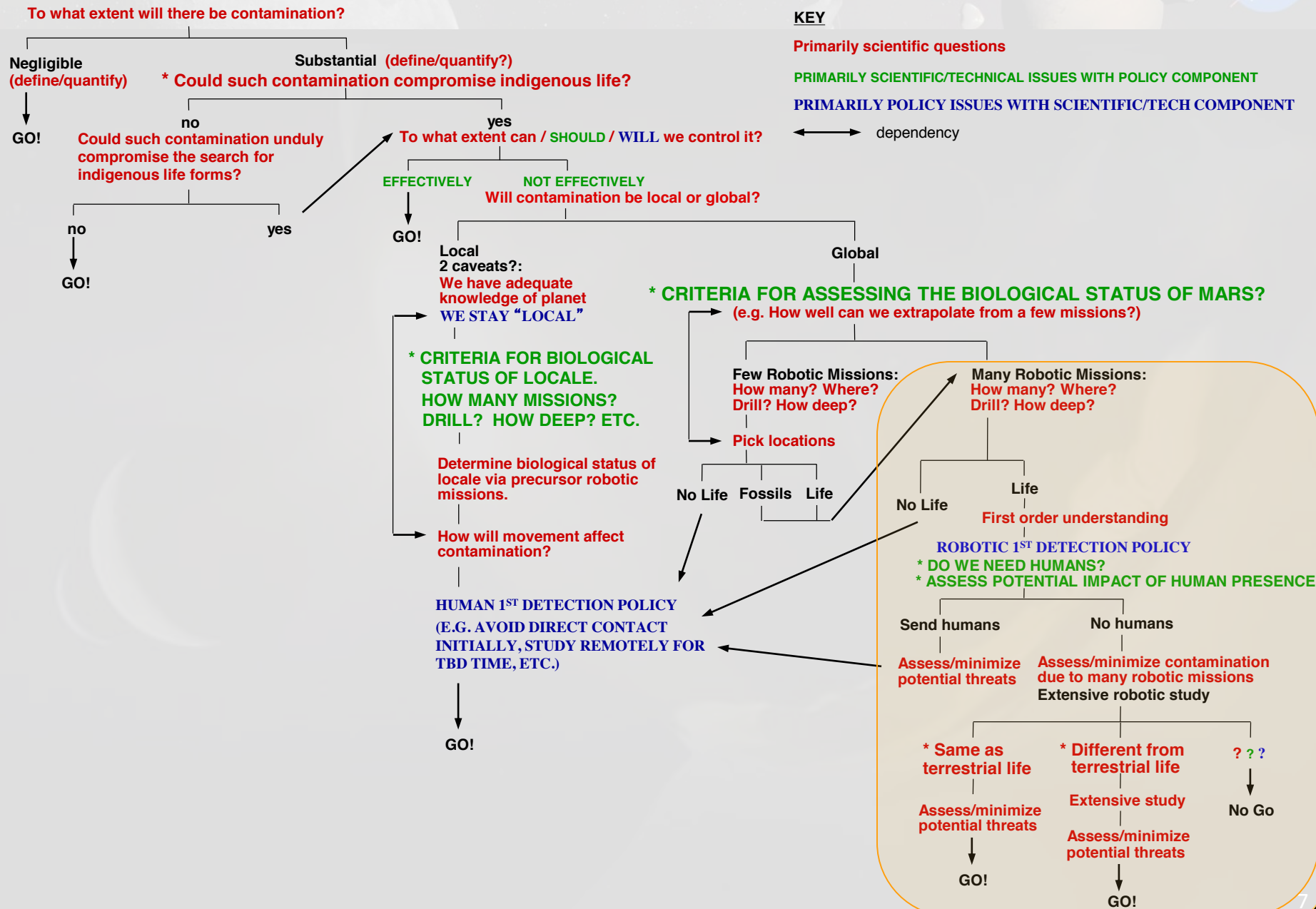


Some PP Guidelines ...



- COSPAR guidelines: “Any uncharacterized martian site should be evaluated by robotic precursors prior to crew access. **Information may be obtained by either precursor robotic missions or a robotic component on a human mission.**”
- NRC Recommendation: “The committee recommends that NASA establish zones of minimal biologic risk (ZMBRs) with respect to the possible presence of Martian life during human missions to Mars. In order to do so, **NASA should conduct a precursor in situ experiment at a location as reasonably close to the human mission landing sites as possible to determine if organic carbon is present. The measurement should be on materials from the surface and down to a depth to which astronauts may be exposed.** If no organic carbon is detected at or above the life detection threshold, the landing site may be considered a ZMBR. If no measurement technique can be used to determine if organic carbon is present above the life detection threshold, or if organic carbon is detected above that threshold, a sample should be returned to Earth for characterization prior to sending humans to Mars. There has been some concern that if a sample return is required, the planning for the first human mission to Mars may be delayed until a sample can be obtained. The committee believes that, even should a sample be required because organic carbon has been found, a baseline mission plan for a mission to Mars and even hardware development may still proceed under the assumption that a sample return will not find anything.”
- HEM-SAG: “After initial evaluation of the state of knowledge about Mars today (circa 2007), the HEM-SAG projected this state of knowledge forward to ~2030, **under the assumption that a robotic Mars sample return mission must be accomplished prior to Human scientific activities on the martian surface.**” But note that this does not say it’s needed at the site humans will land – so we can exclude this or keep it for context?”
- Cassie/Marg recent PP slides: **“Areas around human habitats should be cleared as “Safe” through appropriate robotic exploration, after which human EVA activity would be allowed.”**

Decision tree for mitigating adverse effects to possible indigenous Martian biota from a human mission



A horizontal banner at the top of the slide featuring a collage of space-related images: a small Earth, a large Moon, an astronaut, a Mars rover, and a Mars orbiter, all set against a starry background.

Mars DOT 500 Day Surface Ops Con

The main background of the slide is a dark, atmospheric view of the Martian surface, showing a large, hazy horizon and a crescent moon in the lower left.

Mars DOT 500 Day Surface Ops Con

Mars DRA 5.0 Surface Strategy Options



- Multiple strategies were developed, stressing differing mixes of duration in the field, exploration range, and depth of sampling
 - Mobile Home: Emphasis on large pressurized rovers to maximize mobility range
 - Commuter: Balance of habitation and small pressurized rover for mobility and science
 - Telecommuter: Emphasis on robotic exploration enabled by teleoperation from a local habitat
- Mobility, including exploration at great distances from landing site, as well as sub-surface access, are key to science community
- Pressurized rovers will also bring two small robotic rovers to carry EVA crews, and a drill. They can be teleoperated from the pressurized rover or be given a set of instructions or operate autonomously.
- The human crew's primary EVA job will be to set up a drill that is capable of very deep drilling and operating that device as needed. Should this be done telerobotically?

Mobile Home



Commuter



Telecommuter



MEPAG HEM-SAG Science Operations

General Conclusions



- Requires multiple, independent sites for long-stay for science-driven missions
- Sample mass to Earth > 250 kg, however this is achieved (may include robotic & human return approaches)
- Human horizontal mobility is > 200 km radial (may be up to 500 km radial)
- Vertical mobility should be capable of ~ 300 m (at one site, less at multiple sites on traverses)
- Extant biology is not off-limits, including in situ analysis via special lab equipment
- Requires lab instruments to address multiple objectives
- Science after humans return to Earth is essential for monitoring climate, interior, & astrobiology (if found)
- Some key human science activities on Mars must be demonstrated on the Moon and maybe some on Earth in Mars analogue settings
- Navigational and telecom infrastructure needed to support human science
- Humans on site bring scientific improvisation, adaptability, agility, and increased cognition for solving major problems
- Careful consideration of contamination control and isolation for astrobiology-relevant samples is essential to prevent a “false positives”
- Deep Drilling and long-range pressurized mobility are essential for science-driven HEM missions to Mars
- Robotic assistants are required on field traverses and short-lived monitoring assets

MEPAG HEM-SAG Science Operations

Consensus Conclusions



- Vertical Subsurface Access (drilling)
 - Astrobiology (extant life): ~300 m for access to subsurface liquid water zones (if available)
 - Ionizing radiation/super-oxidant zone is 2-5 m
 - Geology/climate > 100 m access is likely essential (site dependent)
 - Selective Coring (recoverable) vs. pure drilling to depth z (cuttings recovered)
 - Polar climate coring-recovery also at 300 m depth (anywhere deep ice)
- Hab-Lab Requirements (sample analysis) (multidisciplinary)
 - Facilitates high-grading of “sample return to Earth” mass
 - Enables biology-unique (and climate) measurements that cannot be done on Earth
 - Examples of key aspects include: e.g., extant life tests (productivity, labeled radio-C etc.)
 - Monitor environmental isolation (contamination and hab isolation, curation...)
 - Decisions on basis of samples analysis and directs future sample collections and science
- Additional Conclusions:
 - Ensure separation of Astrobiology experiments from human life sciences biology conducted for crew



Mars 500 Day ConOps Guiding Questions



- Mars DOT felt the issues within these guiding questions were significant determinants of Mars crewed surface operations and that a ConOps needed to understand and address these issues and their interactions.
- The guiding questions identified issues regarding the following five topics:
 - 1. Returning Mars samples with the crew**
 - 2. Pressurized cabin operations**
 - 3. Crew waste storage, transfer, and disposal**
 - 4. Nominal crew EVA operations**
 - 5. Sample Handling (on the surface by the crew)**



Guiding Questions: Returning Crew and Surface Samples

- **Notionally, the crew would EVA from the Hab/Lab to a rover, drive the 1 km to the MAV, and EVA again from the rover to the return vehicle — likely carrying the sample container (s) as much as 20 feet up an external ladder to the MAV hatch.**
 - Both the crew's EVA suits and the sample container will have been exposed to the surface
- **Questions:**
 - How do we “break the chain” and get dusty EVA-suited crew into the ascent vehicle?
 - Is it required that crew bring their EVA suits into the ascent vehicle?
 - Can a “layered dust control/containment” system be built into the ascent vehicle?
 - Current suit port design will still have some dust on the PLSS hatch
 - If dust gets into the suits over their 500+ sol surface usage period, it may adhere to the crew's skin or inner garments and be carried into the return vehicle cabin; may require a “crew decontamination” process
 - If we put suit ports on the MAV, do we need one for every crew member (large mass penalty) or can we downsize to 2 or 3 and discard suits before the next crew member goes in?
 - **Do we need to provide decontamination (e.g., suit, crew) before or after leaving the surface?**
Can materials “self-clean”?
 - Could suits be left behind on Mars surface? What about transit EVA needs?



Guiding Questions: Pressurized Cabin Operations



- Pressurized cabins (habitat, rover, ascent vehicle) will have overpressure protection that vents overboard?
- Pressurized cabins will have some nominal leakage of cabin atmosphere + likely off-nominal leakage of fluids
- Questions:
 - Is venting cabin atmosphere overboard or to a closed container required while on Mars' surface?
 - If Mars landing site assessment is adequately done prior to crew landing and transport mechanisms are understood and limited, it might be able to vent while on Mars' surface
 - Otherwise, habitat venting may need to be contained – *precursor landing site data could make the difference in strategy*
 - Does the entire habitat external surface have to be sterilized/cleaned before leaving Earth or just parts the crew may brush against going in/out of the habitat or not at all?
 - If so, how?
 - Habitat will likely be 7- 9 m diameter and may be partially inflatable...can it be sterilized/cleaned in pieces, then assemble?
 - Can the external surfaces be cleaned while the habitat is part of the launch stack?
 - If fluids are inadvertently leaked from lander systems while on Mars' surface (e.g., liquid oxygen propellant; thermal control fluids, such as ammonia or wax; water), does the spill have to be cleaned up?
 - Potentially, yes, at least in the case of water spill or activities that increase local temperatures, to avoid creating a "special region" in the landing zone. Details depend on environment and contamination transport.



Guiding Questions: Logistics & Waste Storage



- **Most of the logistics (e.g., food) will arrive on the Cargo Lander and will be later transferred to the Crew Lander when it arrives**
 - Logistics will be stowed in TBD cargo containers inside a rover or ascent vehicle cabin
- **Questions:**
 - If we have to take the logistics cargo containers outside to transfer from one vehicle to another, do the containers need to be cleaned or sterilized?
 - If so, when? how?
 - Probably doesn't require sterilization?
 - Can some logistics supplies be buried for storage on Mars (e.g., food) to protect it from radiation
 - If so, what kind of container do we need to use?
 - **How do we verify it's safe to bring containers into the Habitat later?**
 - 6 Crew x 500 sols = a lot of empty food containers and a lot of crew waste; since there's not enough room to keep all waste and containers inside, can we dispose of them outside?
 - If so, do we have to do something to them first?
 - Store outside but with TBD cleanliness spec?



Guiding Questions: Nominal EVA Operations



- **Boots**

- EVA crews will likely walk around the landing zone and surface elements
- Crew may also walk in areas where science operations are being conducted (e.g., drill rig)

- **Gloves**

- EVA crews will likely pick up tools, manipulate surface samples (e.g., rocks, core samples), repair equipment (e.g., stalled drill string), and climb up/down ladders/steps to access rovers, habitat, and return vehicle

- **Questions:**

- Do the EVA suits need to be sterilized or cleaned to certain levels before walking on Mars?
 - Requires that sufficient assessment of area can be made prior to crew landing that indicates “lifeless area” and/or consequences of contamination are acceptable?
 - EVA suits will be stowed external to the surface elements (e.g., habitat) and will be exposed to Mars environment (e.g., UV) – is this sufficient to “sterilize/clean” the suit surface? How long do suits need to be exposed for sufficient “sterilization/cleaning”?
 - If yes, where? When working in areas where crew collects science samples or do we need to sterilize/clean before walking around surface elements?
 - If yes, does the entire suit need to be sterilized, or just the parts that nominally touch the surface? Actual contact with Mars is the most important consideration; however, there may be deposition between surface and suit that needs to be addressed.
 - If yes, when/how often? Suits will be stowed inside crew habitat enroute to Mars, so sterilizing on Earth won’t help much. Prior to doing first EVA?
 - If yes, how? Can the outside surfaces be “wiped down” with wet wipes or is it required that the whole suit be “heated”? Note that cleaning may damage the suit, will require a “cleaning capability” and power
 - If yes, do we need to verify cleanliness on Mars? Most probably, yes.



Guiding Questions: Sample Handling

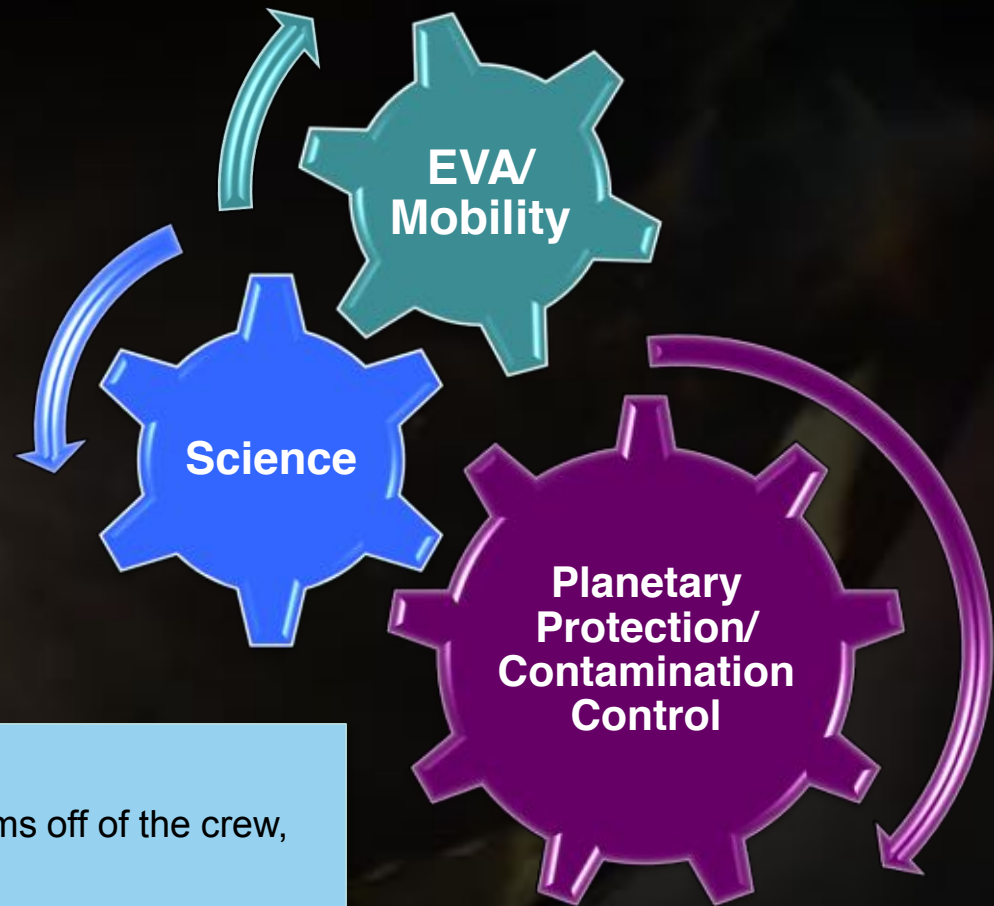


- EVA suits leak internal atmosphere and organic contaminants and may pick up contaminants during crew operations
- Questions:
 - How close can EVA-suited crew member get to surface samples?
 - If contamination can be controlled to acceptable levels, then physical contact with samples should be possible
 - How close to the habitat can samples be transported/stowed?
 - Contamination from habitat may be hard to control, so many samples may need to be kept and analyzed some TBD distance from habitat (e.g., in a separate facility some TBD distance from the habitat accessible by crew or teleoperated)
 - Do we return science samples inside the ascent vehicle's crew cabin or outside?
 - If sample containment is adequate, then sample containers may be stowed inside the return vehicle
 - If inside, does the return container need to be "sterilized" or cleaned prior to transporting to the vehicle without exposing it to the Mars environment again?
 - If outside, the sample containers need to be transported to the return vehicle (e.g., via a crew EVA or robotic transfer)

PP Influences Functional Decomposition & Con Ops



- Can only take Functional Decomposition so far without knowing more about Planetary Protection-Crew Safety-Contamination Control ops con
 - Impacts *how* we do Science
 - Which in turn impacts our EVA and Mobility Strategies and architectures
 - All of which impacts Habitat design and drives overall mission mass



Three related but distinct issues:

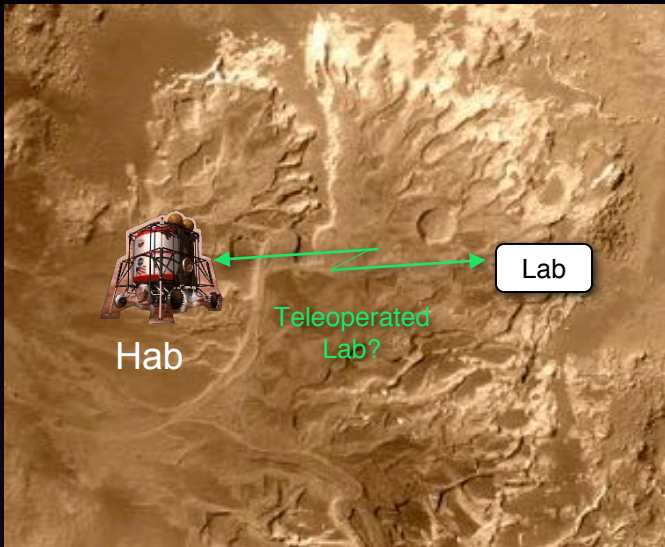
- 1) **Planetary Protection:** Keeping Mars organisms off of the crew, and vice versa
- 2) **Crew Safety:** Keeping toxic dust out of the Habitat/out of EVA suits (regardless of whether there are “bugs” in the dust)
- 3) **Good Science:** Keeping crew/equipment contamination off of Mars science samples

Sample Handling



- Sample handling includes: acquisition, containment, transport & delivery, and analysis, all of which are affected by contamination control, planetary protection, and crew safety.
- If a sample is not from a potential special region, it may be possible send humans into the area to collect the samples.
- Otherwise, alternative methods (e.g., real-time telerobotic sample acquisition and analysis) may be required to avoid the threat of introducing terrestrial biota into the special region.
- Or, if contamination can be sufficiently controlled, crew may be able to enter sensitive areas to acquire samples directly?

Mars Laboratory & Sample Handling

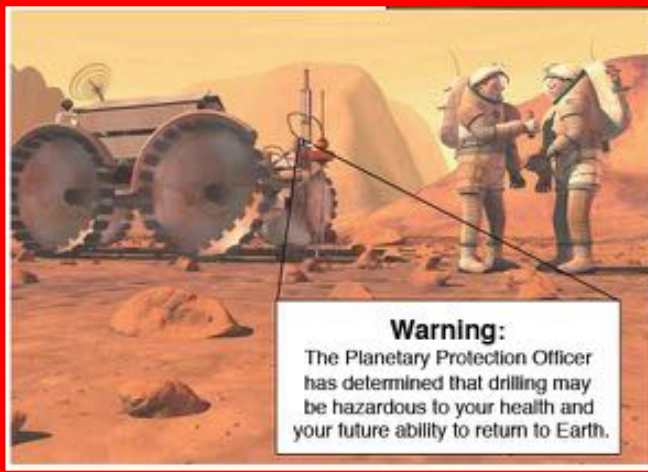


Technical Challenge

- Mars Samples
 - How to collect & contain?
 - How to handle & how to transport?
 - How & what to analyze?
 - Sample curation needs?
- Mars Analytical Laboratories
 - Types?
 - Located where?
 - How do labs fit into science strategy?
 - Lab outfitting?
 - Special Issues: e.g., maintain contamination control, manipulate samples

- **Samples are required across science disciplines**
 - Geology requires surface and shallow subsurface samples
 - Atmospheric & Climate Science requires atmosphere & surface samples
 - Astrobiology has most difficult sampling requirements: 250 – 300 m subsurface (requires drilling) to subsurface aquifer (potential for Mars extant life)**
 - Geophysics requires emplacement of instrumentation & data returned
- **Representative instrumentation was identified**
 - Some sensors and analytical instrumentation development may be required
 - Microminiaturized analytical instrumentation from biotechnology industry may be leveraged
- **Distributed analytical capability required in rover, downhole during drilling, at habitat area, and “glove-size” for EVA crew**
 - Small analytical laboratory in rover, used during traverses
 - Downhole sensors required for data collection during drilling for subsurface samples
 - Small handheld instruments by EVA-suited crew
 - More capable analytical capability at habitat area: **Separate astrobiology lab for analyzing Mars subsurface samples probably required**
- **Issues to be addressed**
 - Sample handling: collection, containment, transport, analysis, curation
 - Contamination control: specifications & protocols required; in-situ cleaning
 - Planetary Protection & Special Regions operations: Leakage, transport, inducing special regions
 - Crew Safety: protocols required, impact on surface element design.

Integrated Drilling Strategy



Technical Challenge

- DRA 5.0 specifies 1,000 kg of drilling equipment. Is that enough?
 - How many holes?
 - How deep?
 - How far apart?
 - Are we drilling into “habitable zones”?



- **Drilling >5m invokes “Special Region” considerations?**
 - DRA 5.0 invokes “Zones of Minimum Biological Risk”
 - ...should we be deep drilling?
- **Subsurface planetary protection guidelines need review, update, and mission specific interpretation**
 - Per COSPAR: surface is self-sterilizing, no constraints down to 5 m?
 - But *ice may be only 3-5 m below surface w/in 30° of equator*
- **None of 53 drill technologies surveyed are a sure thing for 300m target depth**
 - Only 5 drills are advertised >100 m (none demonstrated beyond 3m)
 - Only 1 drill is advertised to 300 m target depth (demo to 3 m, TRL 2)
- **At demo drilling rates, it may take more than 500 sols to drill 300 m**
 - Solvable with tech dev, more power, or autonomous drilling before crew arrives



Integrated Drilling Strategy Recommendations



- The time-scale for a drill to encounter difficulties is often on the order of 10 to 20 seconds, making teleoperation from Earth risky. Teleoperation from Mars orbit or Mars surface is feasible, but risk will vary with drill design and drilling conditions.
- Technology development emphasis should be placed on:
 - automated core and fluid acquisition and handling
 - low mass borehole stabilization,
 - rugged and high-temperature sensor development and placement
 - automated drilling control software
- A high fidelity mass and operational timeline analysis should be completed to determine whether it makes more sense to perform this activity on a crewed vs. robotic mission. Partially underway...
- Mass should be allocated for automated and/or telerobotic control for deep drilling systems (including power).



Follow-On Mars Surface Ops Con Focused Studies



Analyses showed the importance of a set of special topics that could be implemented as forward work. These analyses would address issues that would impact how the Mars DRA 5.0 may be modified to increase mission success and reduce risk. These forward work issues include:

1. Mars Drilling (shallow and deep) operations and options
2. Sample Strategy / In situ sample analysis requirements
3. TBD Contingency Operations
4. Quarantine Protocols
5. “Special Regions” strategy
6. Crew Waste Management
7. Mars Precursor Missions
 - Precursor knowledge is important for human Mars missions. NASA has identified a number of “Strategic Knowledge Gaps” to address prior to a crewed Mars mission.
 - NRC recommends “conducting a precursor in situ experiment at a location as reasonably close to the human mission landing sites as possible to determine if organic carbon is present.”
 - Mars DOT considered some plausible mitigation strategies. But DOT chose NOT address potential contingencies during this first round of analysis.
 - Pre-delivered cargo assets (such as robotic assets/rovers) could be used to conduct sample analysis prior to human landing. **If there is concern about the environment after the crew lands, then initial crew surface operations might be conducted via IVA telerobotics from hab?** This could be done during a planned period of crew acclimation that is already accounted for in our present ConOps.

Potential Surface Ops Approaches



Given the possibility for key uncertainties (e.g. biological status) and incomplete environmental data at a crew landing location after crew has landed, 3 broad EVA strategies might be:

1. Immediate EVA: Allow crew to perform EVA as soon as they are ready without sampling outside around hab first

- Accept risk of forward contamination in an area that has life (or extinct life that could possibly be masked by biological contaminants?)
- Accept risk of potential biohazard threat to crew
- Designs that provide robust containment of all relevant contaminants from suit venting, pressurized rovers, etc. could dramatically reduce the forward contamination risk

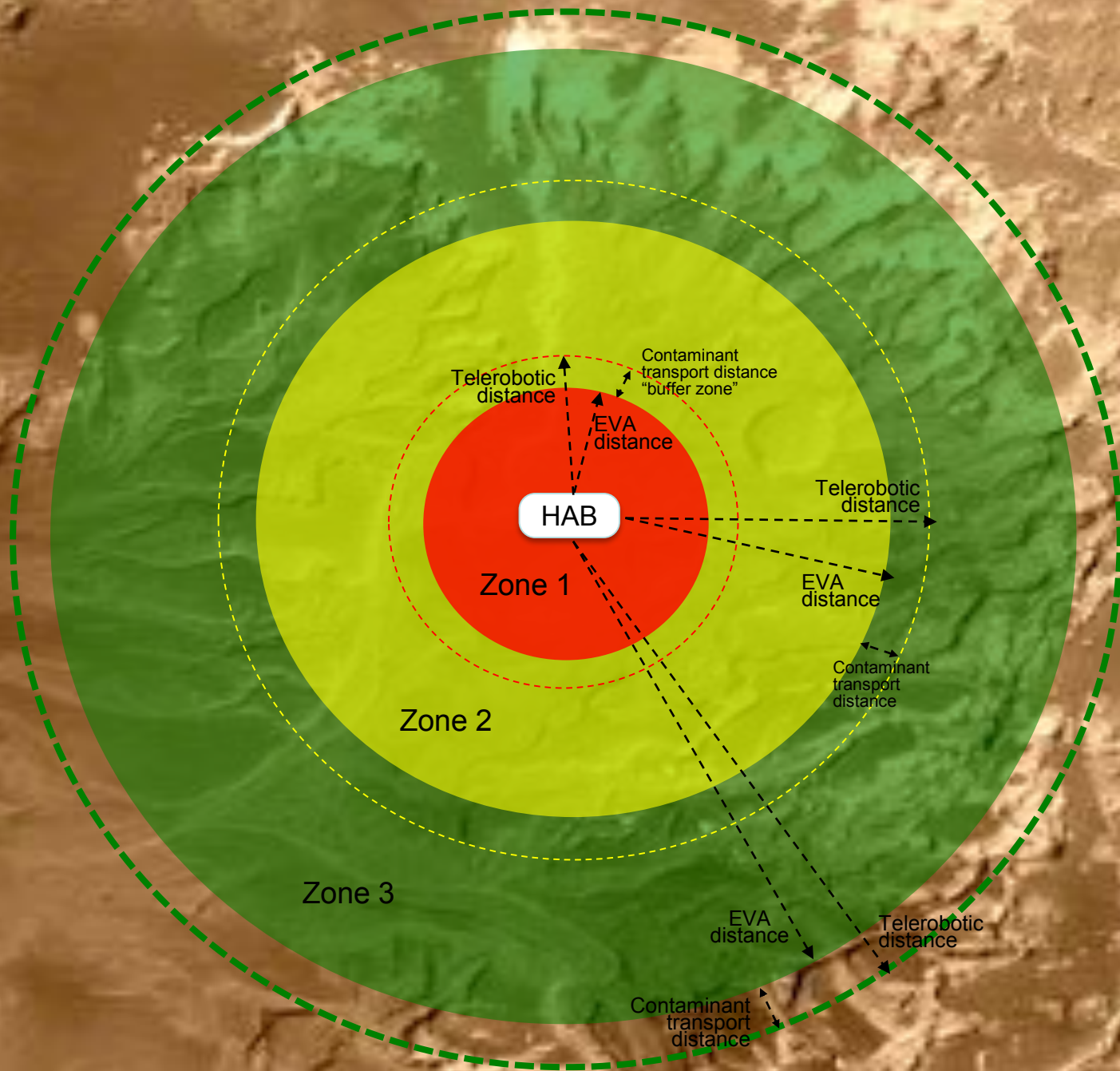
2. Delayed EVA with thorough telerobotic exploration first: Allow crew to perform IVA low-latency telerobotics/tele-science to sample in-situ as well as return samples to hab lab for evaluation prior to performing EVA

- In-situ sampling
- Return samples to lab
- Delay could be very long if thorough analysis is needed over large area

3. Incremental / Proximal EVA: Allow immediate EVA but keep crew and dirty assets close to hab at first and incrementally explore in a “nested” manner with telerobotics and crew

- Assumes long-distance transport mechanisms aren't a problem, but that short distance transport could be

Incremental “Nested EVA”



Crew Assisted Sample Return

Two Basic Concepts:

1. Crew picks up sample pre-delivered to Mars or Lunar orbit and returns with it to earth.
 2. Crew acquires sample themselves via LLT and returns with it to earth.
- * Lunar sample return cases can help prepare for these future missions.
 - * Depending on knowledge at the time, crew-assisted sample return with first Mars sample return may involve undue risk?

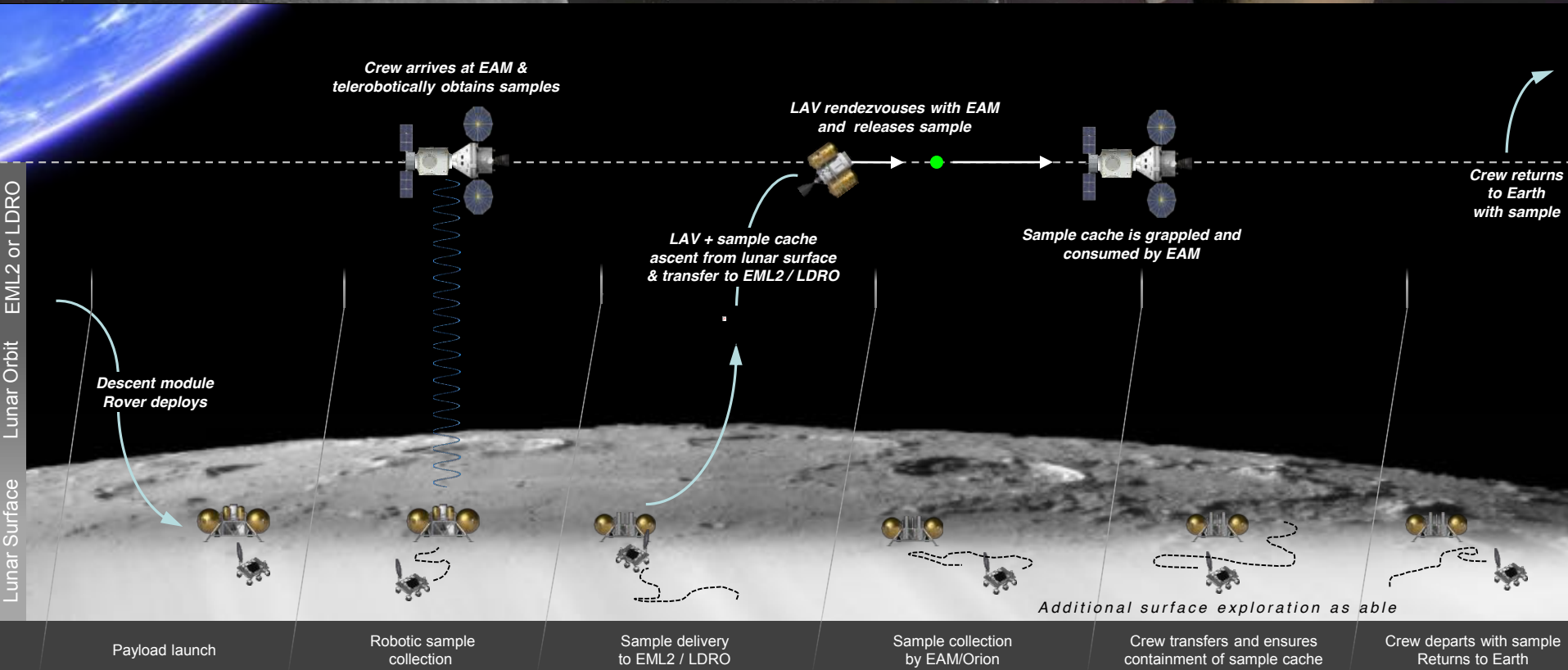


Some Mars Pulls for Lunar Case



- Telerobotic mobility range for landing site recon, prep, sampling
- Telerobotic sample acquisition and analysis on surface. Need better understanding of LLT ops and LLT science ops (e.g. difficulty and time of tasks, “science cognition loop”, etc.)
- Sample acquisition in Mars orbit. **Break sample chain prior to entering Earth-Moon system.**
- Sample containment, including verification methods, time needed, etc.
- Contamination control (e.g. material on sample container)
- **LLT assessment of containment and cleaning of orbiting sample container prior to getting it close to crew vehicle?**

Human-Assisted Sample Return Lunar Vicinity Ops Con



Mission Summary

- After landing at the South Pole/Aitken Basin, the rover is deployed
- The rover identifies, collects, and stores a sample (semi-autonomously or via tele-operations)
- Sample cache transferred to Lunar Ascent Vehicle (LAV)
- The LAV delivers sample canister to EML2 or LDRO and rendezvouses with EAM
- LAV releases passive sample cache
- The sample cache is grappled by EAM and placed in sample airlock
- Sample stored in Orion and returned to Earth with crew

Elements

- Payloads:
 - Descent and ascent modules, rover, sample canister
- Orion + Crew
- EAM

Mission Value

- South Pole/Aitken Basin sample addresses HEOMD Goals & SKGs
- Low-latency telerobotic sample acquisition enables Mars forward activities such as Phobos mission and Mars surface missions
- Planetary Protection feeds forward to Mars missions
- Sample analysis capabilities may also feed forward to Mars missions - TBD

Lunar Surface Teleoperations Ops Con



	2 hrs	2 hrs	2 hrs	2 hrs
Day 11	System Checkout			
Day 12	Drive to Site 1	Analyze Environ.	Drill and Collect Sample	
Day 13	Drill and Collect Sample			
Day 14	Analyze Sample			
Day 15	Drive to Site 2	Analyze Environ.	Drill and Collect Sample	
Day 16	Drill and Collect Sample			
Day 17	Analyze Sample			
Day 18	LLT Maintenance			
Day 19	LLT Maintenance			
Day 20	LLT Maintenance			
Day 21	Drive to Site 3	Analyze Environ.	Drill and Collect Sample	
Day 22	Drill and Collect Sample			
Day 23	Analyze Sample			
Day 24	Drive to Site 4	Analyze Environ.	Drill and Collect Sample	
Day 25	Drill and Collect Sample			
Day 26	Analyze Sample			
Day 27	Store Sample			
Day 28	Drive to ISRU plant	Transfer Sample to ISRU plant		
Day 29	Transfer Sample to ISRU plant			
Day 30	ISRU Demonstration			
Day 31	ISRU Demonstration			
Day 32	ISRU Demonstration			
Day 33	Transfer ISRU products to LAV			
Day 34	LAV Ascent Checkout			

Assumptions:

2.5 km/hr drive speed
 5 km x 5 km search area
 4 sites visited
 12 hrs to drill and collect sample
 8 hrs to analyze sample
 3 days of LLT maintenance
 3 days for ISRU production

Descope Options:

Reduce number of sites
 Eliminate sample return
 Eliminate ISRU demonstration
 Eliminate LLT maintenance

Color Code:

Sample Handling
Driving
Vehicle/System Ops
Analyze Environment

Mission Phase

Mission Phase	Days
Transfer to EML2/LDRO	9
Arrival Operations	1
EAM Teleoperations	24
LAV Transfer from surface	4
Sample Collection in EAM	1
Sample Containment Analysis	3
Other EAM Operations	5
Sample Transfer to Orion	1
Departure Operations	1
Transfer to Earth	11
Total	60
Total in EAM	39
Total in Orion	21

Mars Sample Capture Module ("Sample Airlock")



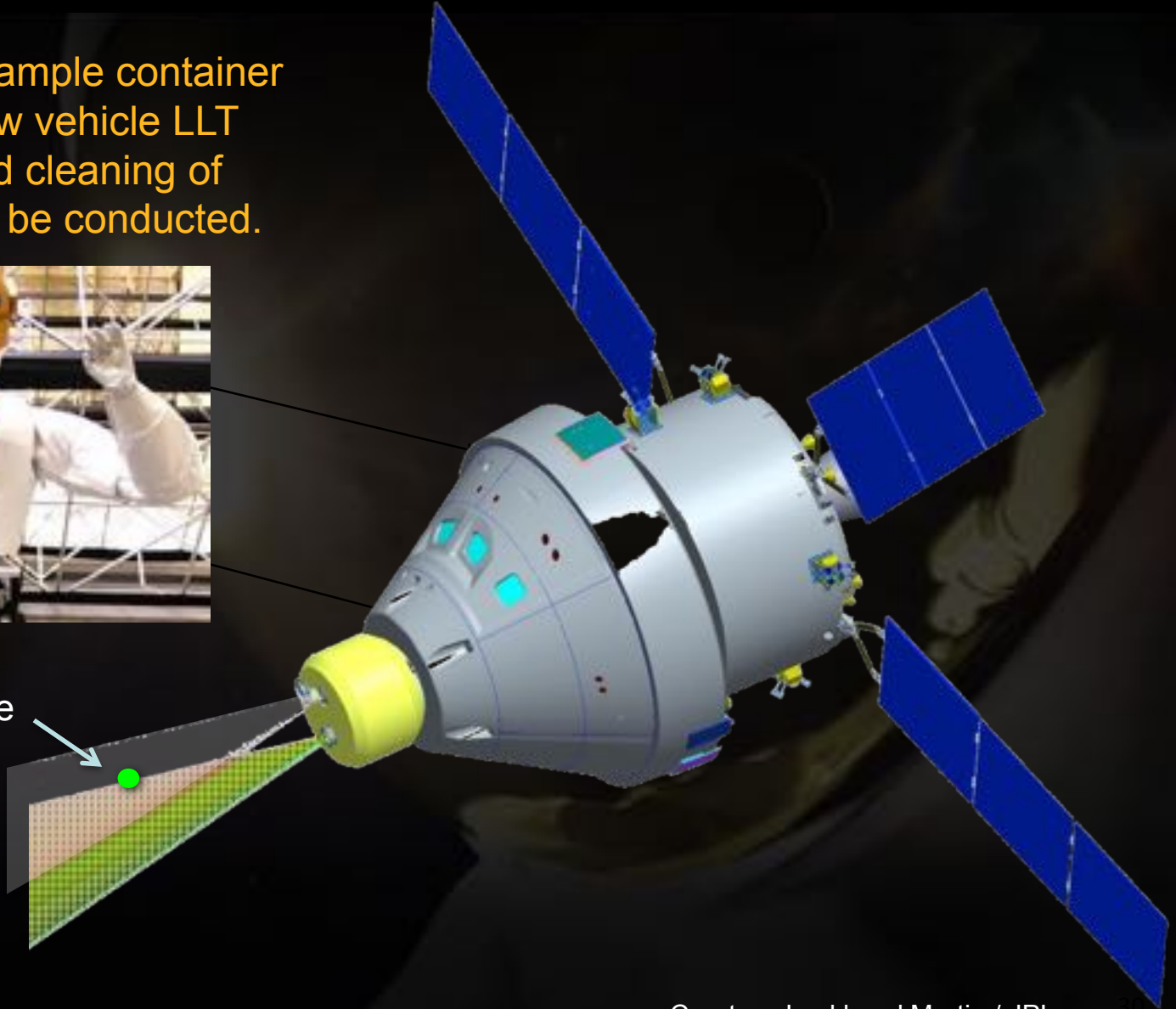
Before orbiting sample container gets close to crew vehicle LLT assessments and cleaning of containment can be conducted.



Orbiting Sample

Camera
field of view

LIDAR
field of view



Courtesy Lockheed Martin / JPL

Planetary Protection

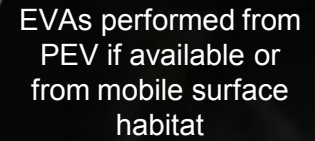
- Bringing crew into proximity with first Mars sample may introduce undue PP risk: e.g. ensuring outside of containment unit is extremely clean, dealing with a sample containment breach, sick crew, etc.
- Crew assisted sample return might be better for future missions after Mars samples are better understood and when larger sample sizes may have more value.
- Sample return may have significant Orion requirements (e.g. sample monitoring, jettison, crew quarantine, etc.). If no chance of meeting those rqmts, then mission concept probably not viable for initial Mars sample returns.
- If sample containment and crew risks are low enough and/or exceeded by potential value (e.g. reliable increased sample mass return, SMD cost savings, possibly crew intervention), concept should be evaluated further to ensure sample containment requirements and evaluate trades in more detail – underway.
- “Breaking the chain” with Mars sample is assumed to have happened prior to entering “earth-moon” system, but breaking the chain again in cislunar may have value?
- Low-latency teleoperations can help address numerous planetary protection concerns



Mars Moons, Mars Orbit



Mars Moons, Mars Orbit



1. Surface Habitat(s) delivered in advance by SEP.
2. Habitat may be fixed or mobile on Phobos surface.
3. PEV may also be pre-staged by SEP.
4. EVAs performed from PEV (if available) or Mobile Hab

1. Scouting and preparation of landing sites for human landers
2. Deployment, maintenance, repair of ISRU & FSP
3. Demonstration & testing of surface mobility systems
4. Scientific exploration (on Mars surface and Mars Moons)

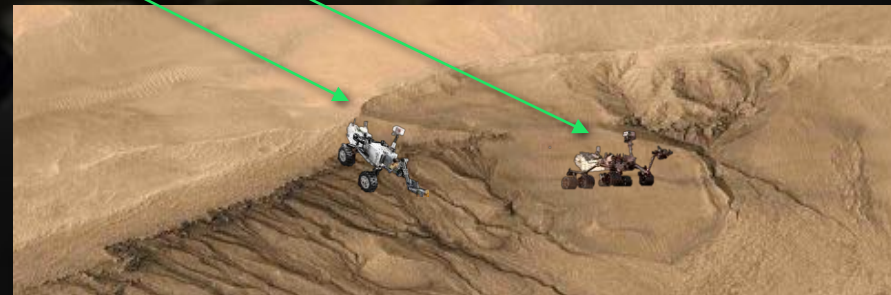
Special Regions Teleops & Potential Sample Return from Mars Moons, Mars Orbit

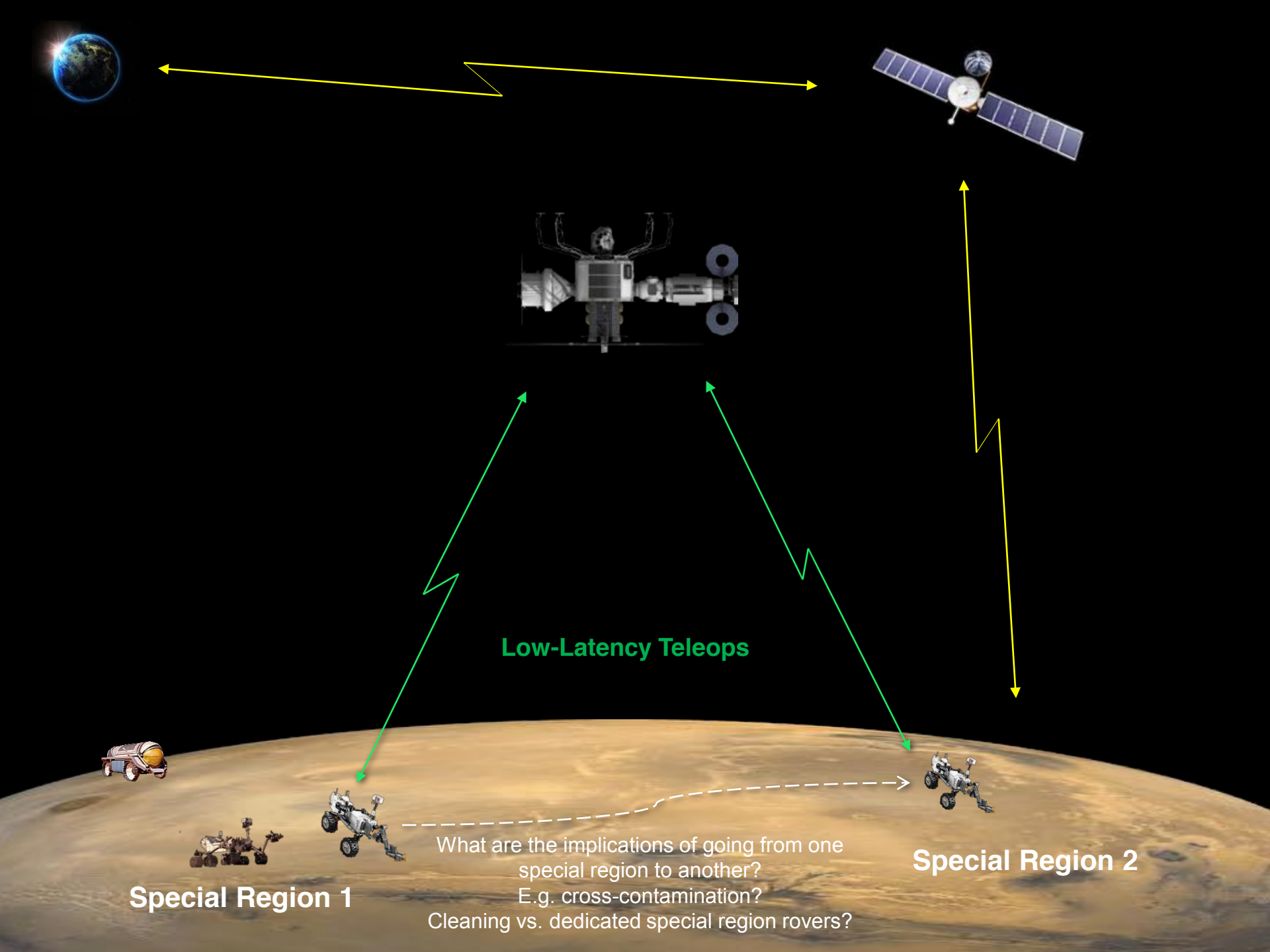


- **LLT from Mars moons/orbit to Mars surface can be used to find and operate within special regions on Mars surface.**
 - Partially address environmental, contamination, and planetary protection concerns by keeping crew off surface until sufficient confidence is obtained to land crew.
 - Practice for doing LLT special region exploration when crew is on surface.



Special Region





Other Potentially Relevant Task Examples:

Surface cleaning and drill bit replacement

(taken from HAT FY14 Telerobotics Task – focused on lunar case and potential Mars feed forward)



- **Task Description: ISRU equipment critical surface cleaning**
 - Clean critical surfaces via brush, compressed gas, vacuum, etc.
 - Examples: solar panels, radiators, MLI thermal blankets
- **Assumptions:**
 - ISRU asset designed for LLT surface cleaning
 - Surfaces accessible by servicing vehicle
 - Contamination detection capability (e.g., camera, sensors)
- **Subtasks for solar panel cleaning representative task:**
 - Disable power and connect common ground
 - Position surface cleaning tool
 - Clean surface and verify cleanliness
 - Remove/stow cleaning tool
 - Inspect panel for cleanliness
 - Repeat cleaning procedure, as necessary
 - Disconnect ground and enable power
 - Perform functional test
- **Challenges:**
 - ESD control
 - Avoidance of other critical components
 - Contamination control (i.e., avoid making things worse)



Photo: Wong GreenTech, <http://wonggreentech.com/category/panels-cleaning>, July 2011

Solar Panel Cleaning timeline



Shift 1	Time >	15m	30m	45m	1h	15m	30m	45m	2h	15m	30m	45m	3h	15m	30m	45m	4h	15m	30m	45m	5h	15m	30m	45m	6h
	Sub Task	Disable ISRU solar array power In/out	Connect common ground line between ISRU and TSR				Unstow TSR cleaning tool/equipment and stage			Activate cleaning equipment & verify ready	Position equipment in proximity to solar panel and secure (if req'd)			Perform cleaning operation						Remove and temporarily stow equipment			Verify/inspect solar panel for cleanliness		
Shift 1 (cont'd)	Time >	15m	30m	45m	7h	15m	30m	45m	8h	15m	30m	45m	9h	15m	30m	45m	10h	15m	30m	45m	11h	15m	30m	45m	12h
	Sub Task	Verify/inspect solar panel for cleanliness (cont'd)	(Repeat previous 4 tasks, as necessary)																	Deactivate and stow equipment			Disconnect ground line		
Shift 2	Time >	15m	30m	45m	13h	15m	30m	45m	14h	15m	30m	45m													
	Sub Task	Stow ground line	Enable ISRU solar array power In/out	Perform solar array functional test																					

- = Telecommand/telemetry to/from ISRU surface asset (ISRU)
- = Robotic operation of Telerobotic Servicing Robot (TSR)

Parts Refurbishment/Replacement



- Task Description: High-wear parts refurbishment or replacement
 - Refurbish or replace high-wear or limited-life components
 - Examples: drill bits, sampler head, filters, soil/regolith hopper seals
- Assumptions:
 - ISRU system designed for parts replacement (standardization, accessibility)
 - “Business end” of resource acquisition devices accessible and grapple-able
- Subtasks for drill bit replacement representative task:
 - Disable power and connect common ground
 - Clean drill head and remove fasteners
 - Remove used bit and stow
 - Install new bit and fasteners
 - Disconnect ground and reenale system power
 - Perform functional test
- Challenges:
 - Contamination control
 - Bit/head securing
 - Alignment, if required



Drill Bit Replacement timeline



Shift 1	Time >	15m	30m	45m	1h	15m	30m	45m	2h	15m	30m	45m	3h	15m	30m	45m	4h	15m	30m	45m	5h	15m	30m	45m	6h
	Sub Task	Disable ISRU drill system power	Connect common ground line between ISRU and TSR				Position drill head for replacement		Clean drill head/bit (as necessary)	Remove drill bit fasteners and stow				Remove used bit & stow			Retrieve & install new bit			Install bit fasteners & secure					

Shift 1 (cont'd)	Time >	15m	30m	45m	7h	15m	30m	45m	8h	15m	30m	45m	9h	15m	30m	45m
	Sub Task	Reposition drill head for operation	Disconnect and stow ground line				Re-enable system power	Peform ISRU drill functional test								

- = Telecommand/telemetry to/from ISRU surface asset (ISRU)
- = Robotic operation of Telerobotic Servicing Robot (TSR)

Implications & Gaps

What Crew Complement is needed?

Crew Cannot Replace Current “Backroom”



Performing in-system teleoperation doesn't replace the “backroom” in Mission Control.

Even if with 2 to 4 highly skilled scientist astronauts, there are still backroom activities that would be useful to perform, including assessments related to planetary protection

However, ability of crew and robots to do more autonomously needs to be pursued, including dynamic science decision-making, implying significant training and advanced information systems.

The backroom performs enabling activities, to include defining daily scientific objectives, monitoring robotic assets performance, processing of instrument data, and detailed engineering (thermal, power, data) analysis.



Moving Expertise & Capabilities In-System



Number of skills & capabilities need to be moved in-system, in addition to all the skills & capabilities required for Mars crewed mission.

Backroom

Current "Backroom" Capabilities



Crew

Capabilities to Move In-System



Extensive Science Knowledge	----->	Some Science Knowledge
Thermal, Power, Data Analysis	----->	Some Thermal, Power, Data Analysis
Model Updates Based on Actuals		
Remote Sensing Data Processing	---->	Some Remote Sensing Data Processing
In-Situ Instrument Data Processing		
Instrument Sequencing & Validation	-->	Some Instrument Sequencing and Validation
S/C Sequencing, Integration, and Validation	-->	S/C Sequencing, Integration, and Validation
Radiation Analysis		
Testbeds		

Candidate Teleoperated Platforms



Platform	Mission/Capabilities
Lander	Mars – includes ascent vehicle for sample return?
Rover	Mars – Sample gathering for return to lander ascent vehicle?
Hopper	Deployed to an initial location and moved to another location(s) during the mission to scout areas of interest for investigation by future robotic landers/rovers
Gecko / Cliff Climber	Deployed to extreme terrain on Martian surface
Penetrator	Deployed into the moons or the Martian surface at locations of interest (greater deployment accuracy by a crew vs autonomous deployment?)
Atmospheric Sample Return	Deployed into Mars' upper atmosphere to collect dust particles and atmospheric gas
Aerial Vehicle	Take atmospheric measurements at varying altitudes on Mars. Local teleoperation may increase the viability of aerial vehicle concepts.
Hybrid Vehicle	For example, an aerobot with deployable mini-rovers



Gaps



1. What planetary protection (PP) related research activities or technical developments do you feel are critical for inclusion in your study area?

Level of criticality TBD:

1. Clean drilling and role of LLT (e.g. cleaning assets, drill bit change-outs, etc.)
2. Borehole measurements
3. Can a small crew effectively execute LLT recon/science? E.g. “quickly” make the decisions they need to make for next steps based on science or other data?
4. Can a small crew effectively execute other important PP-related tasks via LLT from orbit? E.g. cleaning
5. Science lab teleops – can it actually be done effectively?
6. How much area/volume should be explored robotically prior to landing the crew?
7. What kind of pre-landing site/region analysis is needed and at what level of sampling density?
8. How fast can an LLT rover go, including basic ops & science, not just traversing?
9. Should special region assets be cleaned for use in multiple special regions or dedicated to a single special region?

2. What work/research is already underway?

1. HAT high-level mission strategies and concept development underway for a few years
2. LLT is fairly well developed on earth, but not necessarily very clean drilling in natural environments
3. One ISS LLT to earth test has been done. More of that focused on site recon and other science ops could help – concepts being developed

3. Is special information or technology needed to plan for nominal vs. non-nominal situations?
 1. Can small crew respond quickly via LLT to scientifically dynamic situations?
 2. If there is a cleanliness problem, can it be handled via LLT crew actions? E.g. how broad and flexible can LLT cleaning techniques be?
 3. What happens if potential landing sites are found to be special regions? What if life is detected via LLT? Develop basic guidelines or protocols ahead of time?
4. Are existing human mission mitigation options and approaches adaptable for PP needs on the martian surface?
 1. Yes, LLT can be flexible and robust in its application and adaptation to potential needs, particularly with real-time crew control and designs that could cover many use cases. LLT can be used for many things, including PP mitigation.
 2. LLT can be used to find and explore special regions as well as to clean assets if they move between special regions.
 3. Conducting LLT from orbit allows for multiple missions to Mars system to explore moons and safely explore Mars surface prior to crew landing.

5. Are there any significant stumbling blocks ahead that are evident? (Including coordination across PP, science exploration, engineering, operation and medical communities.)
 1. Having the surface assets available to conduct tasks properly over a potentially long time prior to crew landing.
 2. Can LLT truly be effective for human space missions?
6. In your opinion, what still needs to be accomplished?
 1. An understanding of what kind of area/volume should to be explored and with what kind of analyses and sampling density prior to crew landing
 2. An understanding of how much time there will be for LLT activities prior to crew landing
 3. An understanding of how to address potential cross-contamination between locations
 4. Fast integration instruments for surface and subsurface, including life detection
 5. More ISS LLT testing – e.g. LLT science and PP ops testing
 6. LLT activities at the Moon? E.g. farside sample return with Mars like comm delays to earth?
 7. Subsurface planetary protection guidelines need review, update, and mission specific interpretation
 8. Assess broader environmental impact considerations (e.g. along the lines of previous COSPAR / GW SPI workshop?)
 9. Crew Training



Summary

Summary

Activities Enabled or Enhanced by LLT



- **Observation of transient phenomena:** e.g., dust devils on Mars, boundary layer dynamics, life.
- **Operations that benefit from real-time communication:**
 - Drilling, brushing, coring, digging
 - Exploration of extreme terrain: e.g., lava tubes, cliff walls
 - Using unconventional robotic platforms: e.g., aerial vehicles & cliff climbers





Summary: Main Challenging Tasks



- **In-situ Analysis (find, acquire, analyze samples)**
 - Landing site recon
 - Surface
 - Drilling
 - Special regions – find and explore
 - Surface
 - Drilling
- **Science Lab Operations (at TBD distance from hab?)**
 - Life detection
 - Molecular sequencing?
- **Cleaning**
 - Suits
 - Rovers
 - Habitats
 - Sample containment assessment and cleaning in space prior to crew return

Summary: Comparing Orbit LLT with Surface LLT



	Surface Analysis	Lab Analysis	Cleaning
From Mars Orbit	<ul style="list-style-type: none">• Inform crew landing site• Find special regions	<ul style="list-style-type: none">• Inform crew landing site• Orbiting lab?	<ul style="list-style-type: none">• Assess & clean orbiting sample container?
From Mars surface	<ul style="list-style-type: none">• Explore immediate landing site and broader area• Explore special regions potentially with constant direct line of sight without comm relay?	<ul style="list-style-type: none">• Lab positioning relative to hab and other assets could be key• Direct line of sight ops	<ul style="list-style-type: none">• Crew and crew systems being on surface presents additional PP challenges but LLT cleaning could be more important and easier.



Summary Points



- LLT keeps human contamination out but real-time human cognition in
- LLT can help find, explore and protect special regions
- LLT can be used for in-situ analysis as well as lab analysis
- LLT can be used for cleaning assets
- **Gap Summary:**
 1. **Recon rqmts:** Pre- and post-landing site recon requirements, including sub-surface. E.g. may need fast rovers and fast integration instruments for surface and subsurface, including life detection
 2. **Assets:** Will we have surface assets available to conduct tasks properly over a potentially long time prior to crew landing. Can just a few LLT surface assets “do it all”?
 3. **Ops:** Can small crew execute LLT activities, including science lab ops, and other key LLT activities such as cleaning and drilling?
 4. **Time:** Understanding how much time there will be for LLT activities prior to crew landing
 5. **Cross-contamination:** How do we address cross-contamination when moving a rover from one area to another? E.g. Trade in-situ cleaning vs. dedicated special region assets?
 6. **Mars orbit “campaign”:** Multiple Mars orbit missions before landing?
 7. **Life-detection:** If we find life via LLT from orbit and/or while on surface, what then? Develop tentative guidelines sooner than later?
 8. **ISS Testing:** More ISS LLT testing – e.g. LLT science
 9. **Lunar Testing:** LLT PP activities at the Moon? E.g. return sample from far side?
 10. **Environmental Impacts:** Assess broader environmental impact considerations (goes beyond PP as it is today)